Harmonic Motion Imaging (HMI) and monitoring of HIFU treatment in real-time using diverging and plane wave

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Background, Motivation and Objective:
Harmonic Motion Imaging for Focused Ultrasound (HMIFU) has recently been developed to perform and monitor ablation. An Amplitude-Modulated (f_{AM} = 25 Hz) high-intensity focused ultrasound (HIFU) beam is used to induce a localized oscillatory motion at the focus which is simultaneously imaged by HMI. The feasibility of HMIFU in real-time using a 2-D system has recently been shown using a diverging wave to image the oscillatory motion. The objective of this study is to compare the performance of HMI displacement estimation using a diverging wave to that using plane wave imaging in order to achieve real-time capability with a 2D system when ablating canine livers *in vitro*.

Statement of Contribution/Methods:
A 93-element HIFU transducer (f_{center} = 4.5MHz) was used to induce a focal displacement while a coaxially-aligned 64-element phased array (f_{center} = 2.5MHz) was operated using a Verasonics ultrasound system for radio-frequency (RF) channel data acquisition. A continuous 120-s HIFU excitation was performed on two canine liver specimens *in vitro* at 11 different locations total. An unfocused transmit sequence using a diverging wave (5 locations) or a plane wave (6 locations) was used to image the liver at 1000 frames/second. The beamforming was performed using a delay-and-sum algorithm by multiplying a reconstruction sparse matrix by the RF channel data matrix. The data were reconstructed at 80 MHz sampling frequency axially over a 90° angle field of view for the diverging wave and 20 mm width for the plane wave. In order to achieve real-time frame rates, the data reconstruction was performed on a Graphical Processing Unit (GPU). Axial HMI displacements were estimated from the reconstructed RF signals using 1-D normalized cross-correlation and streamed to a graphic user interface at a 1Hz display frame rate.

Results/Discussion/Conclusions:
A localized oscillatory motion was observed at the focusing depth of 70 mm. For all ablation locations in the canine liver *in vitro*, an HMI peak-to-peak displacement decrease was observed between the beginning and the end of the ablation. The average peak-to-peak displacement decrease was (64.9±8.8%). The signal-to-noise ratio in the displacement map (SNR_d) in the region of the focus at approximately 120 s was 22.3±13.3 for the diverging wave and 31.7±12.8 for the plane wave. These results show that HMIFU can provide real-time (1Hz) streaming of displacements simultaneously with HIFU treatment using a diverging wave or a plane wave. The SNR_d was found to be 1.4 times higher using a plane wave than a diverging wave suggesting that plane wave is more applicable for HMIFU. Current ongoing studies include the translation of HMIFU in a clinical setting.
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